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THE DESIGN OF A FLUIDIC OXYGEN INTERMITTENT-DEMAND FLOW DEVICE.(U)
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A laminar flow fluidic intermittent-demand valve for oxygen therapy has been designed and tested to faithfully follow a patient's respiratory cycle. A savings of oxygen from 10 to 67 percent is possible under certain conditions. A small air pump can power the fluidic circuit. Since no moving parts are used other than a diaphragm flow valve, this intermittent-demand valve is expected to be very reliable and require little or no maintenance.

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FIGURES

1. INTRODUCTION

Intermittent flow for oxygen therapy has been shown by Auerbach et al[1] to be an effective way of conserving oxygen and reducing its cost to the patient. By using a prototype of an intermittent-demand flow device made by Bendix Corp., Auerbach et al projected a possible savings of $744.60 per year per patient at a flow rate of 2 liters/min. For thousands of users at home alone, this represents a savings of millions of dollars yearly. Therefore, it is an advantage to use the intermittent-demand flow valve for oxygen therapy. To follow the patient's respiratory cycle, the intermittent-demand device must be able to sense the very small negative and positive pressure ($\pm$ 0.2 mm Hg) in or near the nostrils via a nasal cannula or a face mask. The sensor used in the Bendix device is a spring-loaded diaphragm. It is a very delicate device because it has to sense a very low pressure. Even though Auerbach et al reported that this device has operated without failure for over 150 hr, this is still too short a time for the intended usage.

Researchers at the Harry Diamond Laboratories have developed a fluidic sensing and controlled intermittent-demand valve for oxygen therapy. This report describes its design and performance.

2. DESCRIPTION OF DESIGN

Fluidics has been applied in the design of medical devices such as heart pumps, respirators, and external cardiac compressors.[2,3] The fluidic components used in these medical devices are the turbulent flow types that have a high rate of power consumption and a low signal-to-noise ratio. They are, however, extremely reliable because they have no moving parts. Consequently, their applications in these medical devices have been very successful, but they would not be suitable in the design of the intermittent-demand valve because of their high rate of power consumption and high level of flow noise. This high power consumption would defeat the purpose of the saving of oxygen, and the high flow noise would be objectionable in the hospital and at home. These shortcomings of the turbulent flow fluidic devices have been overcome by a class of second-generation fluidic devices: the laminar flow elements.[4-6] These new laminar flow fluidic elements have a power consumption about three orders of magnitude less than that of the turbulent flow devices, a very low noise figure, and an extremely low threshold. Therefore, these second-generation fluidic elements appear especially suited for the design of the intermittent-demand valve for oxygen therapy.

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[1] *D. Auerbach, M. R. Flick, and A. J. Block, A New Oxygen Cannula System Using Intermittent-Demand Nasal Flow, CHEST, 74 (1 July 1978), 39-44.*

[2] *K. Woodward, G. Mon, J. Joyce, and T. Barila, Fluid Amplifier-Controlled Medical Devices, Proceedings of IRES 17th Annual Conference on Engineering in Medicine and Biology, Cleveland, OH (16-17 November 1964).*

[3] *J. Joyce and G. Mon, A Time-Cycle External Cardiac Compressor, Harry Diamond Laboratories, HDL-TM-68-35 (December 1968).*

[4] *F. Manion and G. Mon, Fluerics 33: Design and Staging of Laminar Proportional Amplifiers, Harry Diamond Laboratories HDL-TR-1608 (September 1972).*

[5] *G. Mon, Laminar Proportional Amplifier, Proceedings of Sixth Cranfield Fluidics Conference, Cambridge, U.K. (March 1974).*

[6] *G. Mon, The Basic Design Concepts of Laminar Flow Digital Logic Elements Using Laminar Proportional Amplifiers with Positive Feedback, Journal of Dynamic Systems, Measurements, and Control, Trans. ASME (March 1979), 77-80*

Figure 1 shows a schematic diagram of this valve. It consists of a laminar proportional amplifier (LPA), a laminar flip-flop, a diaphragm flow valve, a bias control valve, and two pressure regulators. The intermittent-demand valve operates as follows: The flip-flop is initially biased so that the on state is at output 1, and this output pressure causes the diaphragm valve to shut off the oxygen flow to the patient. When the patient initiates the inspiration cycle, his effort generates a negative pressure signal, which is sensed by the LPA via the sensing line. The pressure signal is then amplified by the LPA and causes the flip-flop to switch to output 2. This change of state opens the diaphragm flow valve and allows the oxygen to flow to the patient. This valve remains at its open position as long as the patient is inspiring. As soon as the patient begins the expiration cycle, a positive pressure is detected by the LPA, and this signal is amplified by the LPA and switches the flip-flop. The diaphragm valve is closed, and the cycle is completed. The regulators control the pressure or the flow to both the fluidic circuit and the patient. The bias control valve is used to adjust the level of the switching pressure. To allow a small amount of oxygen to flow to the patient during the expiration cycle, the diaphragm flow valve can be partially opened by adjusting the pressure to the fluidic control circuit. The controlled flow flushes the nasal dead space with oxygen at the beginning of inspiration. In this design, the control circuit and the oxygen flow path are isolated by the diaphragm; therefore, the control circuits can be powered by either oxygen or compressed gas. Since the power consumption for the control circuit is very small, a fish tank pump or other small, low-cost pneumatic supply can be used to power the fluidic circuit.

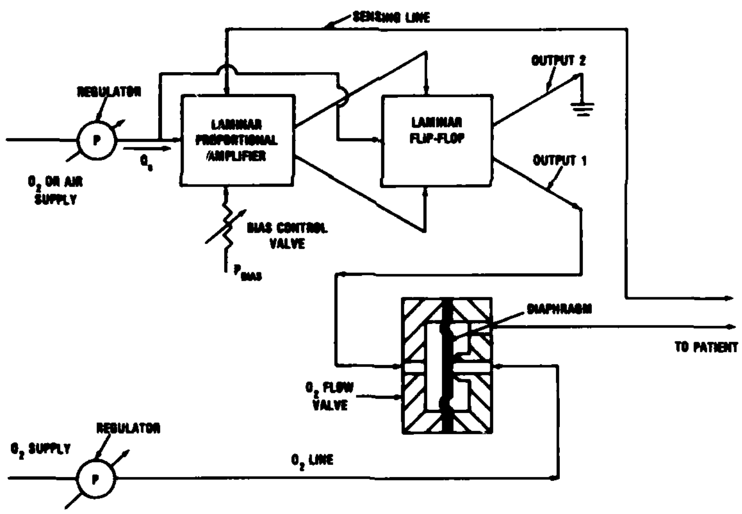

Figure 1. Schematic of fluidic sensing and controlled oxygen intermittent-demand valve.

3. PRELIMINARY TEST RESULTS

A breadboard of the oxygen intermittent-demand valve has been designed and tested. Preliminary observations indicate that this demand valve can faithfully follow the respiratory cycle of the patient. Figure 2 shows a typical trace of the oxygen flow to the patient during inspiration and expiration. Figure 3 shows the oxygen flow rates to the patient and the control circuit at various settings of the flow regulators.

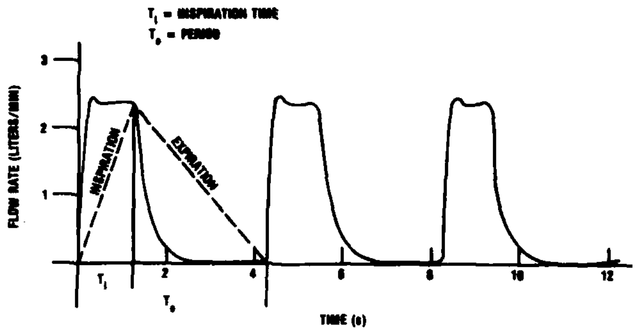

Figure 2. Typical flow pattern during inspiration and expiration.

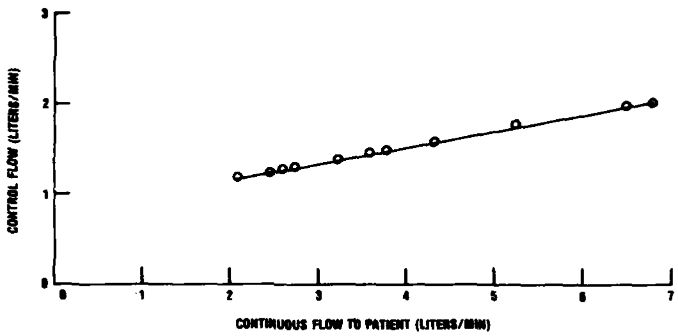

Figure 3. Variations of control flow as function of continuous oxygen flow to patient.

Conserving oxygen is one of the most important performance characteristics of the intermittent-demand valve. The percentage of savings is defined as

$$\text{percentage of savings} = \left(1 - \frac{Q + Q_c}{Q_p}\right) \times 100 \,, \tag{1}$$

where

Q = flow to patient (liters/min),
Q_c = flow to control circuit (liters/min),
Q_p = continuous flow to patient (liters/min).

The flow to the patient can be calculated by integrating the flow curve for each cycle and *dividing it by the period,* T_o. To simplify the calculation, the flow to the patient can be approximated by setting $Q = (1/3)Q_p$ so that equation (1) can be written as

$$\text{percentage of savings} = \left(\frac{2}{3} - \frac{Q_c}{Q_p} \right) \times 100 \tag{2}$$

Figure 4 shows a typical plot of the percentage of savings at various values of Q_p by using the relationship between Q_c and Q_p as shown in figure 3. When the control circuit is powered by an external compressed gas source such as a fish tank pump, Q_c becomes zero, and the savings can be as high as 67 percent.

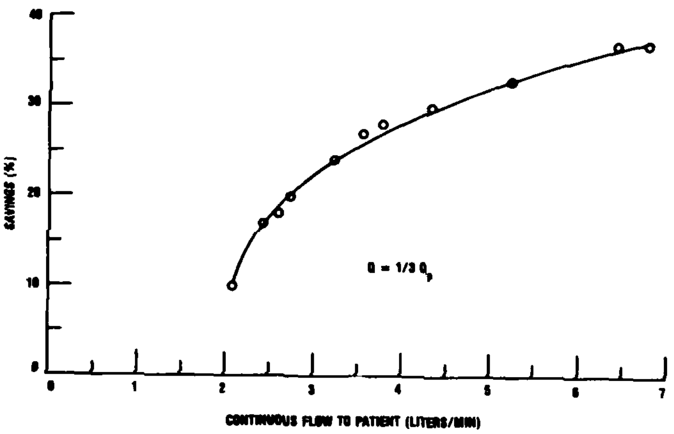

Figure 4. Percentage of savings as function of continuous oxygen flow to patient.

4. SUMMARY

A laminar flow fluidic intermittent-demand valve for oxygen therapy has been designed and tested. Preliminary test observations indicate that this valve can faithfully follow the patient's respiratory cycle. Test results show that a savings of oxygen from 10 to 37 percent is possible when the inspiration is about one-third of the total respiratory cycle and the oxygen supply is used to power the control circuit and valve. When this valve is powered by other compressed gases, savings can be as high as 67 percent. The output of a small fish tank pump is more than adequate to power the fluidic circuit. Since no moving parts are used other than a diaphragm flow valve, this intermittent-demand valve is expected to be very reliable and require little or no maintenance.

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